Exhibit 1 --
Detail Specification for the VTTP for the Touchdown Dynamics Testbed

1.0 Scope

This specification establishes the requirements for the detailed design of the Variable Tilt Terrain Platform (VTTP) to be utilized as part of the Mars Science Laboratory (MSL) Focused Technology program.

1.1 Description

The VTTP is reconfigurable platform designed to provide accurate and repeatable terrain conditions for MSL's Touchdown Dynamics Testbed (TDT). The TDT will be used to perform full scale testing of MSL's skycrane landing technique. A full-scale, medium fidelity rover, referred to as the Touchdown and Mobility Research Vehicle (TMRV), will be integrated with a prototype of the system's bridle assembly. This system will then be subjected to a controlled descent and touchdown via an overhead motion simulator. The purpose of the VTTP is to provide the ability to quickly and accurately vary the terrain characteristics that the test system will encounter during the touchdown event. The VTTP consists of a structural platform with a cavity for carrying granular media. In addition, the platform provides interfaces for the integration of terrain pallets containing rocky terrain. The entire platform assembly is gimbaled about its center, giving the test conductor the ability to pitch the platform to the desired terrain angle. The system can then be easily reset to a new position to facilitate quick turnaround of multiple touchdown scenarios. The platform is also sized sufficiently to accommodate larger test article options for future program needs.

1.2 Applicable Documents

The equipment shall be designed to comply with the following codes, standards, and their subordinate specifications:

- 1.3.1 Occupational Safety and Health Act (OSHA), CFR Title 29, Part 1910, Subpart G, 36FR 10466
- 1.3.2 California Code of Regulation (Cal/OSHA) Title 8, Chapter 4, Subchapter 7. General Industry Safety Orders (Sections 3200 - 6184)
- 1.3.3 California Code of Regulation (Cal/OSHA) Title 8, Chapter 4, Subchapter 5. Electrical Safety Orders (Sections 2299 - 2974)
- 1.3.4 Uniform Building Code (UBC)
- 1.3.5 California Building Code (CBC)
- 1.3.6 NFPA – National Electrical Code 2002
- 1.3.7 Latest issue of National Electrical Manufacturers Association (NEMA)
- 1.3.8 ICS 1, General Standards for Industrial Control and Systems
- 1.3.9 ICS 2, Industrial Control Devices, Controllers and Assemblies
- 1.3.10 ICS 4, Terminal Blocks for Industrial use
- 1.3.11 ICS 6, Enclosures for Industrial Controls and Systems
- 1.3.12 Industrial Fasteners Institute Fastener Standards (IFI)

1.3.13 SAE-J429 - Mechanical and Material Requirements for Externally Threaded Fasteners
1.3.14 AWS D1.1, Structural Welding Code, Steel
1.3.15 AWS D1.2, Structural Welding Code, Aluminum
1.3.16 AWS D1.3, Welding 1/8" Low Carbon Steels
1.3.17 IEEE 519, Harmonics in Power Systems
1.3.18 IEEE 1100, Powering and Grounding Sensitive Equipment
1.3.19 IEEE 1202, Standard for Flame Testing of Cables for Use in Cable Tray
1.3.20 UL 50, Enclosures for Electrical Equipment
1.3.21 UL 508, Industrial Control Equipment
1.3.22 UL 845, Motor Control Centers
1.3.23 UL 1004, Electric Motors
1.3.24 UL 1581, Standard for Safety Reference Standard for Electrical Wires, Cables, and Flexible Cords
1.3.25 National Fluid Power Association T3.Hydraulic Systems Specifications
1.3.26 US Fed TT-P-1757, Primer Coating, Zinc Chromate, Low Moisture Sensitivity.

1.3 Interface Responsibility

The Subcontractor shall define all facility requirements and then check JPL's drawings to verify compliance with the Subcontractor's requirements. Subcontractor interface responsibilities shall be performed in accordance with **Exhibit 3 - Interface Responsibility Matrix**.

2.0 Design Requirements

The following sections detail the requirements, constraints, and assumptions placed on the VTTP, its interfaces, and its support equipment.

2.1 Drive surface dimensions

The VTTP shall provide a minimum driving surface as configured in Exhibit 2, Figures 1, 2 and 3.

2.2 Overall platform dimensions / characteristics

The overall configuration and dimensions of the VTTP are shown in Exhibit 2, Figures 1, 2 and 3.

2.3 VTTP envelope

All VTTP hardware shall be maintained within an outside envelope as detailed in Exhibit 2, Figures 1, 2 and 3.

2.4 Driving Surface Granular Material

The VTTP driving surface area shall be capable of accommodating a granular material depth of 0.75 m (29.5 inches). The entire bottom of the driving surface cavity shall be treated with a high friction coarse grain grip coat or equivalent as approved by JPL. JPL intends to fill the driving surface area with play sand and rocks.

2.5 Platform material weight / carrying capacity

The VTTP shall be capable of simultaneous support of a full load of wet granular media as well as a complete set of terrain pallets (see section 2.17) covering the entire surface. The terrain pallets shall have a distributed weight of approximately 120 kg/m^2 (w/out pallet structure) resulting in a total load (for the specified driving surface) of 15,840 kg (34,800 lbs). Granular material density shall be 1.5 g / cc when dry and 1.9 g / cc when wet. This translates to a total granular media load of 148,500-188,100 kg (326,700 to 413,820 lbs). When combined with the terrain pallet weight, eight (8) personnel at 136 kg (300 lbs) per person plus 1 test rover at 1,500 kg (3,300 lbs), this translates to a total required carrying capacity of 206,530 kg (454,370 lbs). The VTTP carrying capacity shall have a yield factor of safety of at least 2.0.

2.6 Platform Static Offset Hold Torque:

The VTTP shall be able to hold any given position under the moment created by any center of mass to pivot axis offset of a fully loaded VTTP plus 3,000,000 Nm. applied in the –Y (rotation) direction or 1,000,000 Nm in the +Y (rotation) direction without using any power, for an indefinite period of time (note: 3,000,000 Nm is the estimated moment caused by a partial sand slide when the platform is at high angles).

2.7 Platform Operating Torques:

2.7.1 Nominal Operation: The VTTP actuation system shall meet the speed requirements of paragraph 2.13 under an offset load created by any center of mass to pivot axis offset of a fully loaded VTTP (per 2.5) plus 500,000 Nm in the worst direction.

2.7.2 Sand Slide Recovery Operation: The VTTP shall be able to return from its maximum angular offset of 35 degrees to a level configuration after experiencing a sand slide condition (when the system is pivoted past 30 degrees the sand may slide to the –x side of the platform) characterized by an offset load of up to 3,000,000 Nm. The system is not required to meet the speed requirements of paragraph 2.13 when under this offset load. Supplemental actuation provided as part of the VTTP system may be used to meet this required.

2.8 Mounting Interface:

The VTTP shall interface to a foundation with a flat surface. The subcontractor shall specify the detailed interface to the foundation and provide templates and documentation to allow interface features to be located by JPL. The VTTP shall not protrude below the top surface of the flat foundation.

2.9 Foundation Loading

JPL will be responsible for the design and fabrication of the foundation. The geology of the installation site is not yet known but is expected to be of very low bearing strength (possibly as low as 1000-2000 psf). Some design iteration with JPL of the support structure design may be needed to finalize the foundation and VTTP design.

2.10 Range of motion

The VTTP shall have a range of motion sufficient to tilt the platform to any position between 0 degrees (platform flat) and 35 degrees as shown in Exhibit 2, Figure 3.

2.11 Pivot Point Location
The pivot axis of the VTTP shall exist within the range specified in Exhibit 2, Figure 2.

2.12 Accuracy
The VTTP shall be capable of positioning the platform to within at least +/- 0.5 degree of the desired angle.

2.13 Operating Speed
The VTTP shall be capable of at least one fixed operational speed. The speed may be chosen by the subcontractor to be anywhere between .3 deg/sec and .1 deg/sec. It is desired that the platform have the capability of variable speed operation, but this is not required.

2.14 Platform Stiffness and Secondary support
The VTTP shall be designed to limit the maximum total deflection of the impact point to be less than 0.63 cm (.25 inches) when an impact load of 60,000 N (13,488 lbs) (this can be analyzed as either a static load, or as a dynamic load spread over a 0.25 second period with a half sine pulse profile) is applied at 4.5 meters forward (+x direction) of the pivot axis, normal to the VTTP surface plane regardless of its angle. This can be achieved by platform and actuator stiffness design and/or by the use of a secondary support. If secondary support is used it/they shall be designed to be positioned and locked into place (and subsequently moved or repositioned) by 1 person without any special safety gear, vehicles or tools beyond typical hand tools.

2.15 Position hold
The VTTP shall be designed so that no power or use of secondary support devices is necessary to hold any position within the platform's range of motion.

2.16 Platform Marking
The VTTP shall provide visual markings at incremental locations along the X and Y directions of the platform. Labeled tick marks shall be located every 0.5 meters along the perimeter of the driving surface. Tick marks shall be applied with high contrast paint and shall be wear and weather resistant. A single ¼-20, tapped through-hole shall be located at each tick mark to facilitate pre- and post-test measurement techniques. The final marking scheme shall be approved by JPL.

2.17 Personnel support
The following VTTP features shall be incorporated into the system design and implementation to facilitate test personnel needs and safety requirements.

2.17.1 Access areas
The VTTP shall be accessible from both the + and –Y sides of the platform. On the +Y side of the platform, the VTTP shall provide vertical ladder access to the driving surface. On the –Y side, personnel access shall be provided by the TDT facility itself. The VTTP guard rail on the –Y

side shall have a hinged lockable gate (exact location to be determined with JPL).

2.17.2 Handholds / railings

The VTTP shall provide handrails around the entire outside perimeter of the platform (not the driving surface). The handrail height, geometry, and structural characteristics shall comply with all relevant California Building Code (CBC) and OSHA standards. The full height of the guard rails shall be designed to prevent tools, terrain pallet components, and any other items larger than 2.5 cm from being inadvertently kicked off and dropped from the platform deck area. The handrails along the +x and –x ends of the VTTP shall be either removable or collapsible to the driving surface in order to facilitate platform operations. The +x end guard rails shall be able to be angled inward and locked at a 55 degree angle (35 degrees up from being laid flat onto the VTTP). See paragraph 2.28.5. Final configuration of the hand-rail system shall be approved by JPL for the purpose of ensuring compatibility with the surrounding gantry system.

2.17.3 Tie-off points

The VTTP shall provide tie-off points for personnel anchoring during operations at high platform tilt. Hard points for such anchoring shall occur every 1.22 m (48 inches) around the perimeter of the platform. Each anchorage shall be capable of supporting a minimum dead weight of 5000 pounds per person attached to the anchorage point.

2.17.4 Personnel work surface

The VTTP shall have a personnel work surface as specified in Exhibit 2 Figures 1 and 3. The personnel work surfaces shall have of a high friction surface to allow walking and minimize the possibility of a slip or fall from the platform, especially when at full tilt. The walking surfaces shall not allow sand to fall though to the area below the VTTP. All walking surfaces shall be designed to personnel loading consistent with all relevant Building Codes and OSHA standards.

2.17.5 Personnel protection

Hardware pinch or trip points shall be eliminated or adequately shielded to avoid personal injury during operation or maintenance activities. If any VTTP pivot hardware extends above the walking surface, it shall be fully enclosed and shielded to protect the hardware from debris and to protect workers from the hardware.

2.18 Terrain Pallets

The VTTP shall be capable of being reconfigured to allow for testing in terrains other than granular media. To facilitate this capability, the subcontractor shall provide terrain pallets able to support varying geometries of rocky terrain. These pallets shall be maneuverable by overhead crane and easily integrated with the VTTP's granular material in place

2.18.1 Example Implementation

NOTE: THE EXAMPLE OUTLINED BELOW IS PROVIDED ONLY AS ONE POSSIBLE IMPLEMENTATION OF THIS PART OF THE VTTP. The Subcontractor may propose an alternate implementation more suited to their overall VTTP approach as long as the requirements that follow are met.

The following outlines an example implementation of terrain pallet integration to the VTTP top deck. In this example, the driving surface is covered with a set of 22 terrain pallets, each measuring 3 x 2 meters square. Configuration of the example terrain pallets on the VTTP is shown in Exhibit 2, Figure 4. Perimeter pallets are held in position by means of a box beam lip on all four sides of the driving surface (shown in magenta in Figures 4, 5 & 6). As seen in Figure 5, pallets are secured to the driving surface perimeter by means of an interface plate or multiple plates (shown in black). Securing pallets to each other occurs at corner interface points, as seen in Figure 6. A corner interface plate (shown in black) connects four pallet corners together, helping to secure the entire terrain surface in place. The pallets are placed in position directly on top of the granular media previously integrated into the VTTP. Prior to pallet installation, the granular material level shall be smoothed to a level sufficient to allow access to the support pedestals. The support pedestals and the terrain pallet thickness (not including rocky surface) will place the top surface of the pallets to within +/- 1.27 cm (0.5 inches) of the top surface of the box beam lip.

Terrain pallets and their integration hardware are stored and transported as shown in Figure 7. Pallets are stored underneath the VTTP driving surface on rolling carts and are moved into a staging position for lift to the driving surface. The pallet's lift points are located at the four corner interface positions of the structure. The TDT's facility crane will lift the pallet from the staging area to the driving surface for integration to the VTTP.

2.18.2 Terrain Pallet Configurations / Capacities

Type 1 Configuration: The Subcontractor shall provide a terrain pallet capable of supporting the weight of a uniform rocky surface. This rocky surface shall consist of concrete or rock of a uniform thickness of 5 cm with a density of 2.4 g / cm^3, which results in a uniform pallet load of 1177 Pascals (0.17 psi). The pallet with attached rocks shall be designed to support its own load when being lifted from its interface positions, located at the pallet's four corners. (Note: Construction of the pallet is the responsibility of the Subcontractor. Integration of the rock surface shall be the responsibility of JPL)

Type 2 Configuration: A second pallet configuration shall be capable of supporting the integration of a single large rock weighing 1133 kg (2500 pounds) with a footprint of .78 m^2, plus a distributed rocky surface of uniform thickness of 5 cm with a density of 2.4 g / cm^3, across the remainder of the pallet surface area (excluding the large rock) for placement within the driving surface. The pallet shall have a footprint equal to that of the type 1 configuration. This pallet configuration does not need to be designed to allow lift of an integrated rock from the four corner interface positions (lifting will be done through the rock itself), but does need to be designed to support the full weight of the rock when resting on the granular media as well as any relevant test loading as specified in this document. (Note: Construction of the pallet is the responsibility of the Supplier. Integration of the large rock shall be the responsibility of JPL)

Each pallet configuration shall have an overall size and shape that allows for simple integration to the driving surface and storage beneath the VTTP. A gap size of no more than 6.35 mm (1/4 inch) is allowable between pallets. The Subcontractor shall provide enough type 1 pallets with pallet to pallet and pallet to platform interfaces to completely cover the driving area with a uniform driving surface, plus 2 extra pallets, and 6 of the type 2 pallets. The entire bottom of each terrain pallet shall be treated with a high friction coarse grain grip coat or equivalent as approved by JPL.

2.18.3 Interface to VTTP Driving Surface

The VTTP shall provide a capability for securing terrain pallets to the perimeter of the driving surface. The pallet interface shall be sufficient to support both the pallet weight (at all platform angles) and touchdown loads as specified in this document. The method utilized to secure the pallet components to the drive surface interface (i.e. bolt, pin, etc.) shall be easily connected and disconnected and shall be robust to sand, debris, frequent usage, and heavy handling.

2.18.4 Pallet-to-Pallet Interface

The VTTP terrain pallets shall be capable of being connected to each other to provide full support and prevent slippage or motion during touchdown and traverse testing. The pallet interfaces shall be sufficient to support both the pallet weight (at all angles) and touchdown loads as specified in this document. The method utilized to secure the pallet components to the drive surface interface (i.e. bolt, pin, etc.) shall be easily connected and disconnected and shall be robust to sand, debris, frequent usage, and heavy handling.

2.18.5 Impact Load

All elements of the terrain pallets and their interfaces shall be designed to not yield during a test article impact of 60,000 N normal to the surface, distributed over $0.06m^2$ surface area, and a load tangential to the surface of (60,000 N)(sin30)(FS=1.5)=45,000N

2.18.6 Support Pedestals

Removable support pedestals shall be incorporated to support the pallets at their corner junctions. The pedestals shall be affixed to the bottom of the driving surface cavity in the locations shown in exhibit 2, figure 6 . The pedestals shall be designed for ease of integration and de-integration. The pedestals shall be designed to support the 60,000 N impact load but not the 45,000 N tangential load.

2.18.7 Terrain Pallet Installation

A full set of terrain pallets shall be capable of being integrated or de-integrated using a workforce of no more than five (5) trained facility staff in no more than 2 work days.

2.19 Storage

Storage for TDT support and test equipment shall be provided as part of the VTTP system. Details of this storage space shall be as follows:

2.19.1 Terrain Pallet Storage

The subcontractor shall provide a system for storing the terrain pallets and all of their associated installation hardware, beneath the driving surface when the pallets are not in use. The storage system shall lie within the envelope as specified in exhibit 2, figure 1 and shall provide sufficient space so that no pallets are resting on top of each other with the exception of discrete corner blocks or the equivalent. The subcontractor shall also provide transport of pallets from the storage location to the area accessible by the TDT's facility gantry crane immediately adjacent to the +x side of the VTTP, see exhibit 2, figure 9. An example implementation is shown in exhibit 2, figure 7. The subcontractor shall also provide foundation interface requirements to JPL on or before the dates specified in the statement of work.

2.19.2 Enclosed Storage

The subcontractor shall provide an enclosed storage area sufficient to contain and secure the rover test article and other sensitive support equipment. This enclosed area shall provide full protection from inclement weather. The storage area shall have a minimum envelope as specified in exhibit 2, figure 8. In addition, the enclosed area shall have a lockable door with an accessible opening, preferably through a roll-up door. This opening shall have dimensions consistent with those outlined in exhibit 2, figure 8. Additional enclosed storage area for storing tools and other equipment, attached to or separate from the rover garage area, is desired but not required.

2.19.3 Lifting Gear

The subcontractor shall provide all necessary lifting and hoisting gear including custom spreader bars (if necessary) and pallet interface hardware to allow the movement of the terrain pallets with the TDT gantry crane. All such gear shall adhere to the standards and requirements stated and referred to in this document. The lifting gear shall be compatible with a hook height of no more than 1.5 meter above the surface of the terrain pallet.

2.20 Drainage

The platform's granular material cavity shall be designed to drain any water inadvertently collected during an exposure of the platform to the worst case rainfall for the Los Angeles basin as specified by the appropriate building codes. Design of this drainage system shall be sufficiently robust to prevent clogging by the platform's granular material and shall not allow release of the platforms granular media. The particle size distribution of the granular media is that of commercially available play sand, with a nominal particle size of 250 – 450 m and a minimum size of approximately 75 m. The bottom of the –x edge of the platform shall have extra drainage positioned to allow additional drainage when the platform is at an angle.

2.21 Sand Slide Dam

The –x side of the VTTP shall incorporate a sand slide dam as illustrated in exhibit 2, figure 10. The sand slide dam shall ensure that sand with an angle of repose of >= 30 degrees does not flow out of the VTTP when the VTTP is at a 35 degree tilt angle. The sand slide dam as well as the –x side of the platform shall be designed to support the overburden load of wet sand bearing against it when the platform is at 35 degrees.

2.22 Terrain Protection

To protect the VTTP driving surface from the elements, the vendor shall provide a waterproof cover of a size sufficient to completely cover the driving surface. The cover shall be designed to prevent granular media from getting wet during rainfall. This cover shall be designed so that it can be installed in less than one hour by 2 people. The cover shall be designed to operate/remain secure under worst case wind and rain conditions as specified by the appropriate building codes. The cover shall be able to be installed without the use of any facility power.

2.21.1 Terrain Cover Storage

The VTTP shall provide a means of storing the terrain cover when not in use.

2.21.2 Terrain Cover Color

The terrain protection cover shall be black in color.

2.20 Equipment Design Requirements

All Equipment shall be designed to meet or exceed the following requirements:

2.20.1 Equipment shall be analyzed and designed using accepted industry standard engineering practices.

2.20.2 Mechanisms and structural elements shall be designed to withstand repeated maximum static and dynamic forces due to normal operation including all worst case loading scenarios (environmental and operational).

2.20.3 Structural elements shall have sufficient stiffness to maintain structural adequacy during all static and dynamic operating modes, regardless of weight distribution and load cases.

2.21 Stress Analysis

The structural design of the VTTP shall be in accordance with the referenced codes and their related specifications as referenced herein. Specifically:

2.21.1 All applicable load cases shall be considered when determining input forces used to analyze the stresses in structural and mechanical components. All equipment, operating or otherwise, shall be designed to withstand the direct and resultant forces from any load case.

2.21.2 All equipment shall be designed with allowable loads and stresses derived from the values obtained from a recognized publication (e.g., AISC) and shall match the material composition, temperature, surface condition, stress application, size and heat treatment of the component being analyzed as closely as possible.

2.21.3 All applicable load factors shall be applied to the input forces used to determine the stresses in structural and mechanical components.

2.21.4 Fatigue design analyses shall be performed on the structural and mechanical components subjected to dynamic loading to ensure the design meets the Operational Life requirements as set forth in Section 2.24.

2.22 Load Cases

The VTTP shall be designed for:

2.22.1 Normal static and dynamic loads generated during normal operation, as well as hard-stop and maintenance modes.

2.22.2 Loads generated by mechanisms at their full-rated speed and torque (e.g., actuators, motors).

2.22.3 Loads generated by operating the equipment at maximum performance levels. This includes the overburden loads of the sand on the –x side of the driving cavity.

2.22.4 If secondary supports, restraints or motion lockout devices are used, the system shall be designed to either prevent operation of the VTTP until the devices have been released, or the VTTP shall be designed so that no damage is incurred by the application of full actuator load with the lockout devices engaged.

2.22.5 Loads generated by any maintenance persons.

2.22.6 Loads generated by special testing requirements (e.g., increased weight, velocity and/or acceleration during cycle testing). These requirements shall be defined in the design phase.

2.22.7 Loads resulting from shipping, handling, installation or maintenance.

2.22.8 Loads generated by any practical combination of loads described above.

2.22.9 Environmental loads as specified by the documents listed in Section 1.3. Note, JPL lies within a seismic level 4 zone.

2.22.10 Changes in direction or motion (e.g. acceleration, velocity) shall not cause damage to the VTTP or test article during normal operation or single point failure events, when operated and maintained in accordance with the Operation and Maintenance Manuals.

2.22.11 All other loads described in this document.

2.23 Operational Environment

The following requirements, constraints, and assumptions pertain to the VTTPs environmental specifications.

2.23.1 Operating Temperature

The VTTP shall be designed to operate in an outdoor temperature of up to 49 C (120 deg. F) and as low as -5 C (23 F) without the need for active cooling, heating or other thermal control.

2.23.2 Outdoor Exposure

The VTTP shall be designed to be capable of sustained operation in an outdoor environment. The VTTP shall be made waterproof and oil proof wherever possible. Where waterproofing and oil proofing is impossible or insufficient, components shall be housed or containerized in a manner consistent with the codes and specifications outlined in Section 1.3. If a housing is proposed it shall have sufficient access to enable servicing and maintenance of the VTTP.

2.24 Design Life

The VTTP shall be capable of operation for at least **ten (10) years** without major refurbishment or lost-time maintenance. The subcontractor should assume 300 operations of the platform through its entire range of motion per year during its lifetime.

2.25 Factors of Safety

The design of all VTTP hardware shall meet factors of safety requirements based on the maximum of the applicable codes and specifications outlined in Section 1.3.

2.26 Electrical / Control System

The following sections outline VTTP requirements, constraints, and an assumption pertaining to the details of the platform's electrical and control system functionality.

2.26.1 Operational Controls

The VTTP shall incorporate a control system for changing the platform tilt setting. The control system shall provide the following capabilities to the test conductor:

2.26.1.1 Ability to adjust the desired tilt angle of the VTTP in increments of **one (1) degree** or less, with a range from 0 to 35 degrees.

2.26.1.2 Ability to vary the platform tilt angle using push button controls.

2.26.1.3 Provides visual telemetry of achieved tilt angle with a tenth of a degree resolution through an analog and/or digital dial clearly legible by the operator of the push button controller.

2.26.1.4 The VTTP control system shall be able to be permanently positioned anywhere within a 10 meter radius of the –Y side pivot. It will be housed in a weather-proof control booth provided by JPL, exact location and distance will be determined by PDR.

2.26.2 Limit Switches and Hardstops

The VTTP shall incorporate limit switches to stop the rotation of the platform if the end of travel position has been reached. The platform shall also incorporate mechanical hardstops in the event of limit switch failure to prevent over-travel. The VTTP shall be tolerant of driving the platform into the hardstops without any damage, in the event of a limit switch failure.

2.26.3 Average Power

The Subcontractor shall specify the average power draw of the VTTP.

2.26.4 Peak Power

The vendor shall specify both the VTTP peak power and the peak power duration

2.26.5 Standby Power

The VTTP shall require no power to hold the platform in any position within its range of motion.

2.26.6 Loss of Power

The VTTP shall be designed so that a total loss of system power, at any time and in any orientation, will result in a safe and stable platform configuration, under all loading cases specified by this document as well as the applicable building codes.

2.26.7 Telemetry and Status

The VTTP control system shall provide visual status and/or diagnostic telemetry of safety features and of any other features critical for normal daily use.

2.28 Safety

The equipment shall be designed so that any failure of the system or any of its components shall not directly or indirectly cause injury to personnel or serious collateral damage to the gantry or adjacent equipment.

2.28.1 Safety Switch

The VTTP shall provide for lock-out/tag-out procedures during operational and maintenance activities to prevent inadvertent operation of the VTTP while personnel are working on or near the equipment.

2.28.2 Warning Systems

The VTTP shall have warning lights which illuminate, indicating imminent motion of the platform, upon initiation of the keyed safety switch enabling activity. At least 4 warning lights shall be placed to be sufficiently visible from all locations around the platform. The subcontractor shall submit for JPL approval the color scheme for warning light indication. An audible warning alarm shall be initiated whenever the platform is in motion.

2.28.3 Master Kill Switch

The VTTP shall have its master power switch immediately adjacent to or as an integral part of the manual control station. This master switch shall have the effect of killing all power to the VTTP.

2.28.4 Remote Kill Switches

The VTTP shall have 4 remote kill switches located near the 4 corners of the VTTP. Activation of any 1 of the 4 kill switches shall have the effect of stopping all motion of the VTTP. Note the exact positioning of the remote kill switches shall be determined in conjunction with JPL.

2.28.5 Collision Interlock

The VTTP control shall incorporate a collision interlock system which will prevent the VTTP from achieving an angle greater than 20 degrees unless the +X side guard rails have been repositioned such that they are angled inward (toward –x, pivoted at their base) by 35 degrees.

2.29.5 Safe-to-Move Features
The VTTP shall incorporate provisions that ensure that it will not move until all elements (eg: gates, lock-outs, secondary support devices…) of the system are in a safe-to-move configuration. If there are more than 4 such features in the system, there shall be a method for quickly identifying the non-conforming elements.

3.0 Implementation

The following sections outline specific requirements and constraints placed on the implementation of the VTTP. All lines and junctions need to be clearly labeled (fluid, electrical, etc.) with voltage and flow direction.

3.1 Bearing Systems

Bearings shall be selected to meet or exceed manufacturer's L10 life criteria for the application. Rolling element type bearing assemblies shall be shielded and allow for periodic lubrication. Sealed and pre-packed rolling element type bearing assemblies are required where contamination damage can occur.

3.2 Fluid System Requirements

3.2.1 All plumbed and actuated equipment shall be provided in accordance with the following minimum general design and component selection criteria:

3.2.1.1 Hydraulic/pneumatic power supply pumps will cease to function when electrical power is removed, but accumulated hydraulic/pneumatic pressure within the equipment will need to be vented or isolated from the actuation component (e.g., actuator, motor) via automatic valves to ensure that all motion stops.

3.2.1.2 U.S. standard (NPT, SAE, ANSI) pipe, fittings and hoses shall be used throughout the design. Metric sizes are allowed, but not preferred. Mixing of metric and U.S. standard hardware within equipment is not allowed (unless pre-approved by JPL in writing). Note: No threaded pipe or NPT fittings shall be used in hydraulic systems. (¼" pipe and NPT fittings for gauges and sensors are allowed.).

3.2.1.3 All manual valves shall be ¼-turn, full-port, isolation rated ball valves (except sample, bleed, test and clean-out). Butterfly-type valves may be provided for line sizes above 3", but must match the line size.

3.2.1.4 All manual valves shall be provided with integral locking features when required for lock-out/tag-out procedures during maintenance activities.

3.2.1.5 A manual valve shall be provided to isolate major components where necessary to allow for service and maintainability (e.g., between receiver and manifold).

3.2.1.6 A manual valve shall be provided to isolate each element from the energy source.

3.2.1.7 A manual valve shall be provided to vent or drain accumulators, storage vessels and receivers (properly sized and orificed for controlled discharge).

3.2.1.8 Gauges shall be provided that display both U.S. standard psig and metric kPa or U.S. standard psig only, at all points requiring monitoring for safety and verification of proper operation or adjustment. The nominal operating value shall be in the middle of the gauge range.

3.2.1.9 Rigid pipe or tubing shall be used to the greatest extent possible. Flexible lines are to be used only in applications where normal motion will generate flexing along a section of pipe or tubing. For components that can be plumbed with 3/8" or smaller I.D. flexible lines this requirement does not apply.

3.2.1.10 Flexible lines shall be kept to the minimum length possible. Flexible lines are allowed to bend in a single axis only, without torsion.

3.2.1.11 Proper routing and management techniques (e.g., clamps, hose carriers) shall be used to ensure lines and hoses are accessible for inspection and maintenance and protected from mechanical damage (e.g., abrasion, impact, excessive bending).

3.2.1.12 Clean-out and/or bleed ports and test ports are required on all manifolds, circuits and at other strategic location; to ensure that all air or fluid can be bled from the equipment.

3.2.1.13 Control valve manifolds and all valves using control feedback (e.g., servo, proportional, analog) shall be located as close to the actuation components as is feasible.

3.2.1.14 Linear actuators shall not be subjected to any side-loads, except loads associated with the weight of the actuator itself. Spherical mounts are required on both ends of linear actuators. Trunnion mounts and other types of single-axis connections are not allowed. Note: Where meeting these requirements is not feasible, a variance may be requested in writing no later than the first design review. Such variances must be pre-approved by JPL in writing.

3.2.1.15 Systems shall be leak-tight.

3.2.1.16 All hydraulic systems shall incorporate a secondary fluid containment system (such as an oil pan) which is capable of containing all of the systems hydraulic oil in the event of a major spill. All of the hydraulic systems shall be located underneath the VTTP to prevent rain-water from mixing with any accidentally released hydraulic fluid that could be present in the secondary containment system. The secondary containment system shall have a manually operated drain valve to allow clean-up.

3.2.2 In addition, all pneumatic equipment shall be designed and installed in accordance with the following minimum general design and component selection criteria:

3.2.2.1 Minimum operating pressure available from the facility will be 80 psig.

3.2.2.2 Components shall be rated for no less than 200 psig.

3.2.2.3 A check valve shall be provided on the inlet of all accumulators and receivers. A properly sized and orificed valve shall be provided to vent or drain accumulators for controlled discharge.

3.2.2.4 Valves provided for drainage of moisture shall be manually operated.

3.2.2.5 U.S. standard (NPT, SAE, ANSI) pipe, fittings and hoses shall be used throughout the design. Metric sizes are allowed but not preferred. Mixing of metric and U.S. standard hardware is not permissible.

3.2.2.6 Manual valves with integral locking features shall be used when required for lock-out/tag-out procedures during maintenance activities.

3.2.2.7 Manual valves shall be provided to isolate major components where necessary to allow for service and maintainability.

3.2.2.8 Gauges at all points requiring monitoring for safety and verification of proper operation or adjustment shall be provided.

3.2.2.9 Proper routing and management techniques (<u>e.g.</u>, clamps, hose carriers) shall be used to ensure lines and hoses are accessible for inspection and maintenance and to protected from mechanical damage (<u>e.g.</u>, abrasion, impact, excessive bending).

3.2.2.10 Systems shall be leak-tight.

3.2.2.11 A proper size/number of filter, regulator (pressure and/or flow) and lubricator (FRL) or applicable combination of these components shall be provided for each subsystem. All such assemblies shall be provided with an upstream isolation, ¼-turn ball valve and a gauge.

3.3 <u>Welding</u>

3.3.1 All weld inspection procedures and reports shall be performed in strict accordance with the referenced specifications, and the requirements specified in the drawings shall be reviewed and accepted by JPL.

3.3.2 All welding shall be performed by either DIN or AWS currently qualified welders per the respective current requirements of DIN welding and steel construction standards or AWS D1.1, 1.2 or 1.3. Exceptions to this requirement may be granted for MIG welding on very low-risk applications, if pre-approved by JPL in writing.

3.3.3 The design of the structure must be sufficient to prevent stress cracking of the welds or parent material for the life of the product as specified in Section 2.24.

3.3.4 High residual stresses in components resulting from manufacturing processes including welding and thermal treatment shall be reduced where possible, or the design shall be such that these stresses are accounted for.

3.4 Fastener Usage

3.4.1 Fasteners shall be specified in accordance with the fastener manufacturer's recommendations for proper application. Bolts shall not be used as pivot points, stub shafts or hinges unless specifically designed for the application.

3.4.2 Non-welded parts shall be connected by structural rivets or through-bolts. Any variances to this requirement must be pre-approved by JPL in writing. Note: For items not intended to be removed for service or maintenance, other bolting methods may be allowed (e.g., blind holes, rivnuts).

3.4.3 Bolted connections shall be designed for SAE Grade 5 or ASTM - A325 hardware and assembled with the same or higher grade.

3.4.4 All nuts, bolts and washers used together shall be matched in grade.

3.4.5 Holes for fasteners shall be machined (e.g., punched, drilled, reamed, tapped) in accordance with the fastener manufacturer's specifications. Torch-cutting is not allowed.

3.4.6 U.S. standard (ANSI, ASTM, SAE) hardware is preferred throughout the design. Metric hardware is allowed if a purchased component is not available with U.S. standard hardware. Mixing of metric and U.S. standard hardware within an assembly is not allowed.

3.5 Electrical Systems

3.5.1 JPL will provide a properly rated and protected electrical service in accordance with the facility input statement provided by the Subcontractor.

3.5.2 The subcontractor shall provide information on total power consumption in KVA, current and operating voltage to enable JPL to size incoming feeder cable and over-current devices.

3.5.3 The subcontractor shall be responsible for providing power distribution from the base of the gantry to all parts of the VTTP that require power.

3.5.4 Equipment electrical service shall be designed in accordance with the National Electrical Code (NEC), including GFI protection where required.

3.5.5 Equipment shall be designed in accordance with the reference documents identified herein, including IEEE 1202, UL 1581 and NFPA 70 and 101.

3.5.6 All wiring shall be NFPA-approved 600-volt cable that complies with UL 1581 and IEEE 1202. Wiring in umbilicals and on the simulators shall be plenum rated cable; wiring in trenches shall be tray rated cable.

3.5.7 Where non-linear loads (e.g., adjustable speed drives) are part of the connected load of a transformer, the transformer shall be k rated (k-13), Equipment shall be provided with harmonic compensation in accordance with IEEE Std. 519 and 1100.

3.5.8 25% surplus capacity shall be provided in wiring in umbilicals and on the simulator (e.g. 15 circuits shall be provided for a 12 circuit connector, with 3 spare circuits.)

3.5.9 All motors and electrical components shall be provided with separate ground wires. Metallic enclosures of electrical equipment shall be provided with means for terminating grounding conductors (metallic enclosures, raceways, etc. shall not be used as sole ground-fault return path).

3.5.10 Cabinet-to-cabinet and cabinet-to-control shall be electrically isolated.

3.5.11 Subcontractor provided equipment shall include all systems and components required to control and distribute power and to ensure the proper performance of equipment. At a minimum, these shall include the following where applicable:

3.5.11.1 Non self-resetting Motor Control Centers (MCCs) – thermal overload and short circuit MCCs are required at a minimum.
3.5.11 2 MCCs shall be uniquely addressed and monitored
3.5.11 3 Disconnects, circuit-breakers, fuses
3.5.11 4 Interposing relays
3.5.11 5 Cabinets and enclosures

3.6 Transportation Restrictions

Due to JPL transportation and space limitations, VTTP delivery and assembly plans shall be approved by JPL.

3.7 On-Site Assembly

The subcontractor is responsible for assembly and installation of the VTTP. The Subcontractor shall provide all documentation, procedures, and on-site support necessary to complete final integration and testing of the VTTP at its final JPL location. The subcontractor shall be able to assemble the VTTP outdoor on-site at JPL, as no indoor facility will be available. The Subcontractor shall develop these processes within the specifications outlined in this document.

3.8 Hardware External Finish

All equipment shall be finished in a manner suitable for extended outdoor storage and use. Paint shall be capable of preventing rust and oxidation on all exposed metal surfaces for no less than 10 years. Externally visible painted surfaces shall be painted in a color scheme approved by JPL.

3.9 Hoisting Gear

Hoisting gear is defined as all equipment used to interface between the crane hook or other lifting device and the hardware to be lifted. Examples include lifting slings, spreader bars, shackles, and adapters. Hoisting gear includes umbrellas or other protective equipment to prevent oil or particulate, generated by the crane or other overhead lifting device, from contacting the lifted hardware.

3.9.1 Sling Assemblies

A sling assembly is defined as a lifting device used for hoisting using one or more legs to attach the load to the lift point.

3.9.1.0 Design Requirements - The following restrictions for sling assemblies used to handle terrain pallets shall apply:

· Natural fiber rope or natural fiber web slings shall not be used.
· Carbon steel or wrought iron chain slings shall not be used.
· Wire rope slings shall be formed with swaged or zinc poured sockets or spliced eyes.
· Wire rope clips or knots shall not be used to form slings.
· Rotation resistant rope shall not be used for fabricating slings.
· All pins shall include a positive locking feature to preclude accidental removal.

3.9.1.1 Factor of Safety - 1) All wire rope sling assemblies shall be designed to meet an ultimate factor of 7. Note that the maximum proof load shall not exceed 1/2 the cable breaking strength. 2) All non-wire rope slings, such as nylon, rope, or fabric, shall be designed to meet an ultimate factor of 10.

3.9.1.2 Sling Proof Testing - A dynamic or static proof load test of all hoisting gear is required.

3.9.1.2.1 Dynamic - A proof load equivalent to 2 times the weight of the terrain pallet (including weight of rocky surface) shall be placed at the pallet-to-lifting gear interface. An additional weight equivalent to the weight of the lifting gear shall also be added to the lifting gear. The dynamic proof load test shall be performed using maximum accelerations and worst case conditions. The proof load shall be held a minimum of 3 minutes.

3.9.1.2.2 Static - A proof load equivalent to 3 times the weight of the terrain pallet plus rocky surface shall be placed at the pallet-to-lifting gear interface. An additional weight equivalent to 2 times the weight of the lifting gear shall also be added to the lifting gear. The proof load shall be held a minimum of 3 minutes.

3.9.1.2.3 Quality Assurance Witness - All proof tests shall be documented and approved by the appropriate QA personnel and by appropriate engineering personnel..

3.9.1.2.4 Proof Tags - Proof test tag shall be tethered to the equipment.

3.9.2 Sling Hooks, Shackles & Eyebolts & Similar Commercially Available Items

3.9.2.0 Design Requirements -

- All pins shall include a positive locking feature to preclude accidental removal.
- All Shackles shall have pins installed in such a manner that they cannot fall out if cotter pin/clip fails.

3.9.2.1 Factor of Safety - A minimum ultimate factor of safety of 5 shall be maintained.

3.9.2.2 Proof Testing - A dynamic or static proof test is required.

3.9.2.2.1 Dynamic Proof Test - Items shall be dynamically proof tested to a load of up to the manufactures recommended maximum proof test value and used at up to 1/2 the tested value. The proof load shall be held a minimum of 3 minutes.

3.9.2.2.2 Static Proof Test - Items shall be statically proof tested to a load of up to the manufacturers recommended maximum proof test value and used at up to 1/3 the tested value. The proof load shall be held a minimum of 3 minutes.

3.9.3 Spreader Bars

A spreader bar assembly is defined as a specifically designed lifting device used for hoisting a load. It consists of a beam used to divert or span the direct load and can include the use of sling(s) in the assembly. Critical welds for Spreader Bar assemblies should be eliminated where possible.

3.9.3.0 Design Requirements - The following restrictions for spreader bar assemblies used to handle critical hardware design requirements shall apply:

1. Natural fiber rope or natural fiber web slings shall not be used.
2. Carbon steel or wrought iron chain slings shall not be used.
3. Wire rope slings shall be formed with swaged or zinc poured sockets or spliced eyes.
4. Wire rope clips or knots may not be used to form slings.
5. Rotation resistant rope shall not be used for fabricating slings.
6. All pins shall include a positive locking feature to preclude accidental removal.

3.9.3.1 Factor of Safety - Spreader bar assembly structural elements shall be designed to meet a yield factor of safety of 3.75 and an ultimate factor of safety of 5. The following applies for spreader bar assembly cable elements. All wire rope sling assemblies shall be designed with an ultimate factor of 7. Note that the maximum proof load shall not exceed 1/2 the cable breaking strength. All non-wire rope slings, such as nylon rope, or fabric, shall be designed with an ultimate factor of 10. The design load shall account for the weight associated with the weight of the spreader bar assembly plus the pallet with rocky surface weight below the crane attach point.

3.9.3.2 Spreader Bar Proof Testing - A dynamic or static proof load test of all hoisting gear is required. For spreader bars with multiple lift points, each point shall be proof tested.

3.9.3.2.1 Dynamic - A proof load equivalent to 2 times the weight of the terrain pallet (including weight of rocky surface) shall be placed at the pallet-to-lifting gear interface. An additional weight equivalent to the weight of the lifting gear shall also be added to the lifting gear. The dynamic proof load test shall be performed using maximum accelerations and worst case conditions. The Proof load shall be held a minimum of 3 minutes.

3.9.3.2.2 Static - A proof load equivalent to 3 times the weight of the terrain pallet plus rocky surface shall be placed at the pallet-to-lifting gear interface. An additional weight equivalent to 2 times the weight of the lifting gear shall also be added to the lifting gear. The proof load shall be held a minimum of 3 minutes.

3.9.3.2.3 Quality Assurance Witness - All proof tests shall be documented and approved by the appropriate QA personnel and by appropriate engineering personnel..

3.9.3.2.4 Proof Tags - Proof test tag shall be tethered to the equipment.

4.0 Documentation

The following sections outline the requirements, assumptions, and constraints placed on the VTTP documentations, interfaces, and certifications

4.1 Documentation Protocol

All documentation provided by the Subcontractor shall be written in the English language. Dimensions shall be provided in both English and metric units, with metric being the primary. Paper copies shall be delivered on 8.5 in x 11 in or 11 in x 17 in paper, or A3/A4 paper with special borders. The documents shall also be provided on PC-compatible DVD in formats readable by Microsoft Office. CAD files will be transferred in a format to be negotiated between the subcontractor and JPL. CAD files will be provided in both native and neutral formats. All document packages require JPL approval.

4.2 VTTP Design Documentation

The Subcontractor shall provide a full set of design drawings of the equipment provided. These shall be of sufficient detail to allow JPL or it's consultants to assess the ability of the equipment to meet the requirements specified herein and to allow JPL to maintain the equipment. Documentation shall be provided in both hardcopy and electronic form as specified in Section 4.1. The package shall include but not be limited to:

4.2.1 Drawing tree
4.2.2 Block diagrams, single line drawings and wiring diagrams

4.2.3 Outline drawings showing overall dimensions, motion and reach envelopes, clearance requirements and electrical, structural and utility interfaces.
4.2.4 Assembly / construction drawings
4.2.5 Parts lists
4.2.6 Detail drawings
4.2.7 Plumbing schematics
4.2.8 Control System Theory of Operation
4.2.9 Wire lists

4.3 Interface Drawings and Documentation

The Subcontractor shall provide a complete set of interface documents to allow JPL to complete the design of the foundation. These documents shall address the following, as appropriate:

4.3.1 Space requirements for the VTTP, support areas, operator's console, maintenance areas, etc., including dynamic motion envelope.
4.3.2 All loads, attachment details, dimensions, locations, orientations and tolerances for all interfacing structures.
4.3.3 Electrical power requirements for power, controls, and other systems, including emergency power or other special requirements.
4.3.4 Facility requirements for any pneumatic or hydraulic power, or any other utilities (gas, water, etc.).
4.3.5 Maintenance requirements including access panel locations, clearance envelopes, catwalk and railing requirements, access corridors for cranes, lighting requirements, hoist locations, etc.
4.3.6 List of JPL-supplied equipment necessary to install and commission the system.

4.4 Performance Verification

The Subcontractor shall document the analysis and operational data used to determine the expected performance of the VTTP.

4.5 Code Compliance

The Subcontractor shall review the codes and standards listed herein, identify which codes have been applied and identify how compliance has been achieved.

4.6 Analysis

The Subcontractor shall compile a list of weights and center of gravity locations for all equipment supplied. Moments of inertia shall also be provided for all moving equipment. The Subcontractor shall also prepare and submit an analysis package consisting of a complete structural analysis of all load-bearing components, a failure modes and effects analysis of the VTTP, and sizing calculations for all pneumatic, electrical or hydraulic equipment supplied. The analysis report shall be stamped by a Professional Engineer licensed in the State of California and submitted to JPL engineering for concurrence.

4.7 Safety Assessment

The Subcontractor shall review the VTTP design to ensure that it meets all relevant hardware and personnel safety specifications outlined in this documents and the documents referenced herein. The Subcontractor shall perform an analysis to demonstrate compliance with this requirement. This analysis shall be submitted to JPL for review and concurrence.

4.8 Acceptance & Proof test plan

The Subcontractor shall write plans for acceptance and proof testing of the equipment both at the Subcontractor's facility and at the site. This test plan needs to be reviewed and approved by JPL. The Subcontractor shall perform these tests in the presence of engineers selected by JPL.

4.9 Spares List

The Subcontractor shall submit recommendations for spare parts inventories to be retained by JPL. The list shall include pricing, sources, and lead times for all listed components.

4.10 Operations and Maintenance Manuals

The Subcontractor shall provide an operations manual and maintenance manual. It shall be of sufficient detail to allow JPL personnel to operate, maintain and repair the equipment safely and efficiently. The Manual shall include functional descriptions of each subsystem, exploded assembly drawings, parts lists, control logic, and flow charts.

4.11 Training Information

The Subcontractor shall provide any documentation necessary to support the training of JPL's operations and maintenance personnel besides the operations and maintenance manuals. The subcontractor shall provide documentation in accordance with **Exhibit 4 – Documentation Submittal Matrix**.

5.0 Screed Option

JPL seeks a terrain maintenance/leveling system that does not interfere with any of the previously stated requirements and can accommodate 2 different VTTP configurations. Since the 2 configurations do not need to be easily interchangeable it is acceptable to take advantage of each configurations characteristics. Configuration 1 (exhibit 2, figure 9) will be the primary configuration and features 6 terrain pallets that will be used as personnel access areas. It is acceptable to incorporate screed features that would bar those 6 pallets from being easily removable. The other, central, pallets will however need to be installed and removed repeatedly while in the VTTP is in configuration 1 and can not be blocked by the screed.

5.1 Screed:

The subcontractor shall provide a screeding system to level the sand between tests. The screeding system shall accommodate 2 VTTP terrain configurations as shown in exhibit 2, figure 9. Configuration 1 will be the primary configuration for several years, configuration 2 will be used to accommodate future missions that are not currently under development. Configuration 1 and 2 in exhibit 2, figure 9 both represent the sand-box mode of operation in which the terrain pallets are not used (except as personnel access areas). The screeding system shall not interfere with the repeated re-configuration of the VTTP between the terrain pallet mode of operation and the sand-box mode of operation.

5.1.1 Sand Leveling

The screeding system shall be capable of bringing a surface with a +/- 15.25 cm sand roughness down to at most a +/- 5 cm roughness from the nominal fill level (water level).

5.1.2 Support Pedestal Accommodation

The screeding system shall be able to operate smoothly and reliably even when the support pedestals are in place. The screed will also be used to level the sand after installing the support pedestals prior to installing the terrain pallets.

5.1.3 Guide Rails

If guide rails are used they shall run in the x direction of the VTTP.

5.1.4 Screed Storage

When not in use the screed should be stored in manor that minimizes the impact to VTTP personnel operations, terrain pallet integration and testing. Some loss of required driving surface area or personnel access area is acceptable but should be minimized.

5.1.5 Operation

The screed shall be operable by two trained individuals.

5.1.6 Use of Gantry Crane

There will be a 3 ton gantry crane that can be used to manipulate and assist in screed operations. The specific crane has not been identified so details regarding its maximum side loading is not available. If the gantry crane is to be used, it should be used in a manor that minimizes side loads into the crane and does not impose additional requirements on the crane design itself.

5.1.7 Applicable Requirements

All aspects of the screed system shall meet all relevant requirements stated or referred to in this document.